Harmonic detection and filtering

n°4

$$PF = \frac{1}{\cos\varphi\sqrt{1 + THD^2}}$$

$$P = \sum_{h=1}^{\infty} U_h I_h \cos\varphi_h$$

Schneider Electric
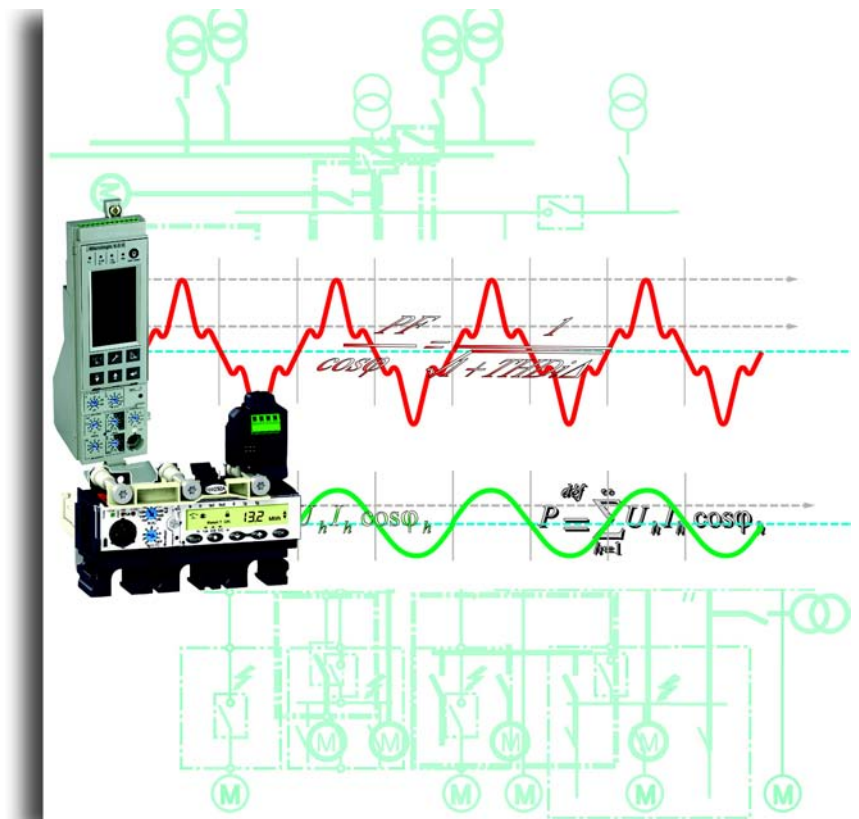
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General

1.1 Definition of harmonics and their origin

1.1.1 Distortion of a sinusoidal signal

The Fourier theorem states that all non-sinusoidal periodic functions can be represented as the sum of terms (i.e. a series) made up of:
■ a sinusoidal term at the fundamental frequency
■ sinusoidal terms (harmonics) whose frequencies are whole multiples of the fundamental frequency
■ a DC component, where applicable.

The ***nth order harmonic*** (commonly referred to as simply the nth harmonic) in a signal is the sinusoidal component with a frequency that is n times the fundamental frequency.

The equation for the harmonic expansion of a periodic function is presented below:

$$y(t) = Yo + \sum_{n=1}^{n=\infty} Y_n \sqrt{2} \sin(n\omega t - \varphi_n)$$

where:
■ Yo: value of the DC component, generally zero and considered as such hereinafter
■ Yn: rms value of the nth harmonic
■ ω: angular frequency of the fundamental frequency
■ φ_n: displacement of the harmonic component at t = 0.

Example of signals (current and voltage waves) on the French electrical distribution system:
■ the value of the fundamental frequency (or first order harmonic) is 50 hertz (Hz)
■ the second (order) harmonic has a frequency of 100 Hz
■ the third harmonic has a frequency of 150 Hz
■ the fourth harmonic has a frequency of 200 Hz
■ etc.

A distorted signal is the sum of a number of superimposed harmonics.

Figure 1 shows an example of a current wave affected by harmonic distortion.
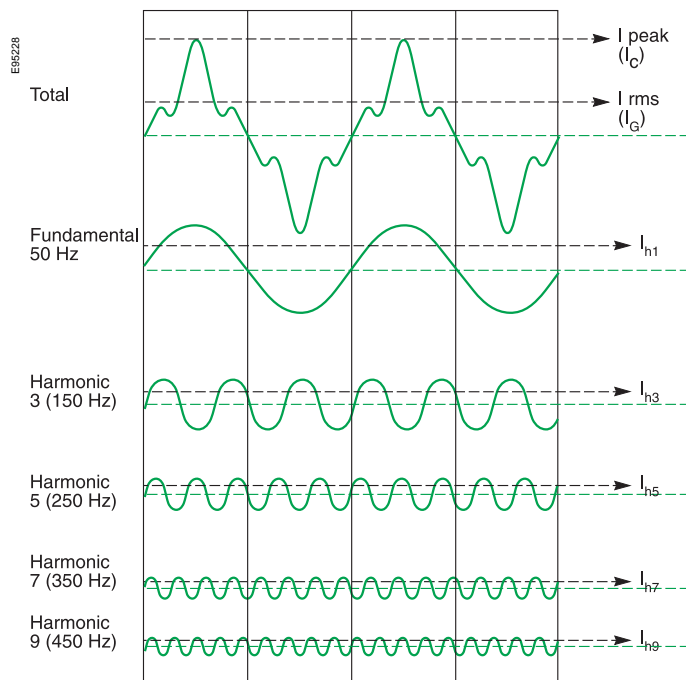
Figure 1 - *Example of a current containing harmonics and expansion of the overall current into its harmonic orders 1 (fundamental), 3, 5, 7 and 9.*

General

Representation of harmonics: the frequency spectrum

The frequency spectrum is a practical graphical means of representing the harmonics contained in a periodic signal.

The graph indicates the amplitude of each harmonic order.

This type of representation is also referred to as spectral analysis.

The frequency spectrum indicates which harmonics are present and their relative importance.

Figure 2 shows the frequency spectrum of the signal presented in figure 1.
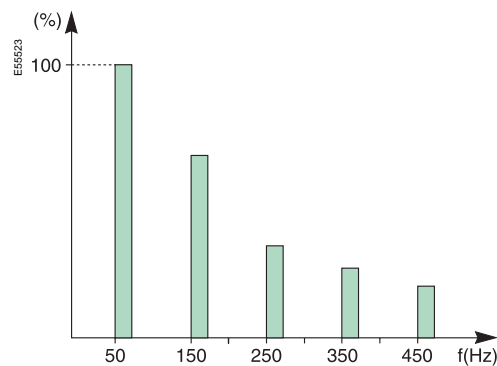
Figure 2 - *Spectrum of a signal comprising a 50 Hz fundamental and harmonic orders 3 (150 Hz), 5 (250 Hz), 7 (350 Hz) and 9 (450 Hz).*

1.1.2 Origin of harmonics

Devices causing harmonics are present in all industrial, commercial and residential installations. Harmonics are caused by *non-linear loads*.

Definition of non-linear loads

A load is said to be **non-linear** when the current it draws does not have the same wave form as the supply voltage.

Examples of non-linear loads

Devices comprising **power electronics** circuits are typical non-linear loads.

Such loads are increasingly frequent and their percentage in overall electrical consumption is growing steadily.

Examples include:
- industrial equipment (welding machines, arc furnaces, induction furnaces, rectifiers)
- variable-speed drives for asynchronous and DC motors
- office equipment (PCs, photocopy machines, fax machines, etc.)
- household appliances (television sets, microwave ovens, fluorescent lighting, etc.)
- UPSs.

Saturation of equipment (essentially transformers) may also cause non-linear currents.

Disturbances caused by non-linear loads, i.e. current and voltage harmonics

The supply of power to non-linear loads causes the flow of harmonic currents in the distribution system.

Voltage harmonics are caused by the flow of harmonic currents through the impedances of the supply circuits (e.g. transformer and distribution system a whole in figure 3).
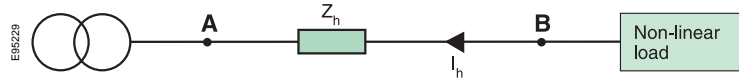
Figure 3 - *Single-line diagram showing the impedance of the supply circuit for h-order harmonic.*

Note that the impedance of a conductor increases as a function of the frequency of the current flowing through it. For each h-order harmonic current, there is therefore an impedance Z_h in the supply circuit.

The h-order harmonic current creates via impedance Z_h a harmonic voltage U_h, where $U_h = Z_h \times I_h$, i.e. a simple application of Ohm's law. The voltage at B is therefore distorted and all devices supplied downstream of point B will receive a distorted voltage.

Distortion increases in step with the level of the impedances in the distribution system, for a given harmonic current.

Flow of harmonics in distribution systems

To better understand harmonic currents, it may be useful to imagine that the non-linear loads reinject harmonic currents upstream into the distribution system, in the direction of the source.

Figures 4a and 4b show an installation confronted with harmonic disturbances. Figure 4a shows the flow of the fundamental 50 Hz current, whereas in 4b, the h-order harmonic current is presented.
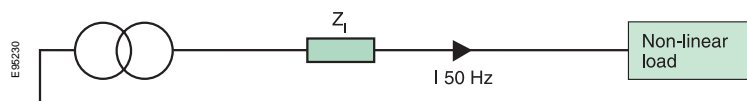
Figure 4a - *Diagram of an installation supplying a non-linear load, showing only the fundamental 50 Hz current.*
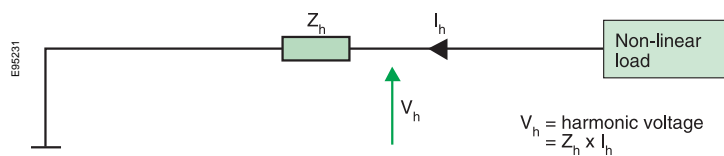
Figure 4b - *Diagram of the same installation, showing only the phenomena related to the h-order harmonic.*

Supply of this non-linear load causes the flow in the distribution system of current I_{50Hz} (shown in figure 4a) to which is added each of the harmonic currents I_h (shown in figure 4b) corresponding to each harmonic (order h).

General

Using once again the model of non-linear loads reinjecting harmonic currents into the distribution system, it is possible to graphically represent this phenomena (figure 5).
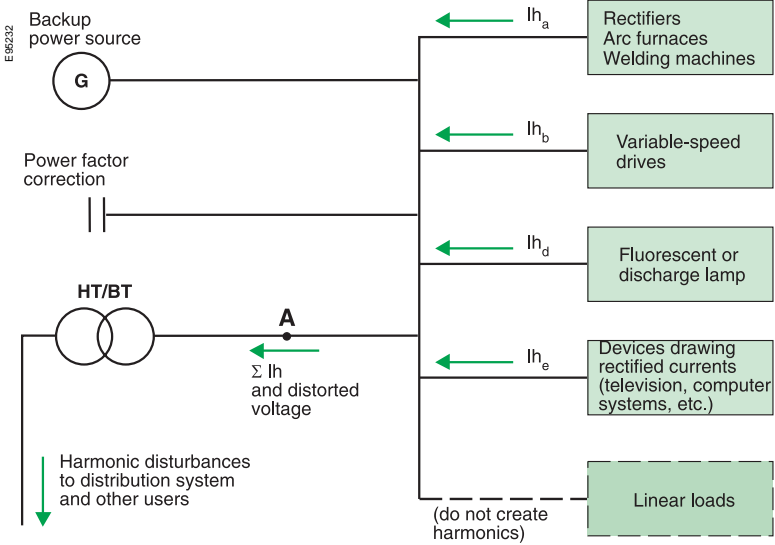
Figure 5 - *Flow of harmonic currents in a distribution system.*

Note in this figure that certain loads cause harmonic currents in the distribution system and other loads are disturbed by them.

1.2 Why harmonics need to be detected and suppressed ?

1.2.1 Disturbances caused by harmonics

In distribution systems, the flow of harmonics reduces power quality and consequently causes a number of problems:
- overloads on distribution systems due to the increase in the rms current
- overloads on neutral conductors due to the summing of third-order harmonics created by single-phase loads
- overloads, vibrations and premature ageing of generators, transformers, motors, etc., transformer hum
- overloading and premature ageing of capacitors in power factor correction equipment
- distortion of the supply voltage, capable of disturbing sensitive loads
- disturbances on communications networks and telephone lines.

1.2.2 The economic impact of disturbances

Harmonics have a significant economic impact, in that:
- premature ageing of equipment means that it must be replaced earlier, unless it was oversized to begin with
- overloads on the distribution system mean the level of subscribed power must be increased, with additional losses, unless the installation can be upgraded
- distortion of the current provokes nuisance tripping and shutdown of production equipment.

These **extra costs in terms of equipment, energy** and **productivity** all contribute to reducing the competitiveness of companies.

1.2.3 Increasingly serious consequences

As recently as ten years ago, harmonics were not considered a major problem, because their effects on distribution systems were, generally speaking, relatively slight. However, the massive increase in the use of loads employing power electronics has significantly worsened the situation in all fields of activity.

Harmonics are all the more difficult to reduce in that they are often caused by equipment that is vital to the operation of companies.

1.2.4 Practically speaking, which harmonics must be measured and reduced ?

The harmonics most frequently encountered (and consequently the most troublesome) on three-phase distribution systems are the odd-order harmonics (3rd, 5th, 7th, etc.).

Beyond the 50th order, harmonic currents are negligible and measurements are not required.

Sufficient accuracy of measurements is obtained by taking into account harmonics up to the 30th order.

Utilities monitor harmonic orders 3, 5, 7, 11 and 13.

It follows that conditioning of harmonics is imperative up to order 13 and ideally should include harmonics up to order 25.

A number of indicators exist that may be used to quantify and assess the harmonic distortion of current and voltage waves.

These indicators are:
- the power factor
- the crest factor
- the distortion power
- the frequency spectrum
- harmonic distortion.

These indicators are indispensable in determining any corrective action required.

The essential indicators of harmonic distortion and measurement principles

2.1 Power factor

The power factor will be noted "PF" in this document.

2.1.1 Definition

The power factor is the ratio between the active power P and the apparent power S.

$$PF = \frac{P}{S}$$

In electrical jargon, the power factor is often confused with cosine phi (cos φ), which may be defined by the equation:

$$\cos\varphi = \frac{P_1}{S_1}$$

P1 = active power of the fundamental.
S1 = apparent power of the fundamental.

As the above equation makes clear, cos φ applies only to the fundamental frequency. When harmonics are present, its value is different than that of the power factor.

2.1.2 Interpreting the value of the power factor

An initial indication that significant harmonic distortion exists is provided when the measured power factor is not equal to cos φ (i.e. the power factor is less than cos φ).

2.2 Crest factor

2.2.1 Definition

The crest factor is the ratio between the value of the peak current or voltage (I_m or U_m) and the corresponding rms value.

$$k = \frac{I_m}{I_{rms}} \quad \text{or} \quad k = \frac{U_m}{U_{rms}}$$

For a sinusoidal signal, the crest factor is therefore equal to $\sqrt{2}$.

For non-sinusoidal signals, the crest factor can be greater than or less than $\sqrt{2}$.

This factor is particularly useful in drawing attention to exceptional peak values with respect to the rms value.

2.2.2 Interpreting the value of the crest factor

A typical crest factor for the current drawn by non-linear loads is much greater than $\sqrt{2}$. Its value can range from 1.5 to 2 or even up to 5 in critical situations.

A very high crest factor indicates that high overcurrents occur from time to time. These overcurrents, detected by the protection devices, may cause nuisance tripping.

2.3 Power and harmonics

2.3.1 Active power

The active power P of a signal distorted by harmonics is the sum of the active powers corresponding to the voltages and currents in the same frequency order. The expansion of the voltage and current into their harmonic components may be written as:

$$P = \sum_{h=1}^{\infty} U_h I_h \cos \varphi_h$$

where φ_h is the displacement between voltage and current of harmonic order h.

Nota :
- *it is assumed that the signal does not contain a DC component, i.e. $U_0 = I_0 = 0$*
- *when the signal is not distorted by harmonics, the equation $P = U_1 I_1 \cos \varphi_1$ again applies, indicating the power of a sinusoidal signal, where $\cos \varphi_1$ is equal to "$\cos \varphi$").*

2.3.2 Reactive power

Reactive power applies exclusively to the fundamental and is defined by the equation:

$$Q = U_1 . I_1 . \sin \varphi_1$$

2.3.3 Distorsion power

Consider the apparent power S:

$$S = U_{rms} . I_{rms}$$

In the presence of harmonics, the equation becomes:

$$S^2 = \left(\sum_{n=4}^{\infty} U_h^2 \right) . \left(\sum_{n=1}^{\infty} I_h^2 \right)$$

Consequently, in the presence of harmonics, the equation $S^2 = P^2 + Q^2$ is no longer valid. The distortion power D is defined as $S^2 = P^2 + Q^2 + D^2$, i.e.:

$$D = \sqrt{S^2 - P^2 - Q^2}$$

The essential indicators
of harmonic distortion
and measurement principles

2.4 Frequency spectrum and harmonic content

2.4.1 Principle

Each device causing harmonics has its own harmonic-current "fingerprint", with different amplitudes and displacements.

These values, notably the amplitude of each harmonic order, are essential elements for analysis of harmonic distortion.

2.4.2 Individual harmonic distortion (or harmonic distortion of order h)

Individual harmonic distortion is defined as the level of distortion, in percent, of order h, with respect to the fundamental:

$$u_h(\%) = 100\frac{U_h}{U_1} \quad \text{or} \quad i_h(\%) = 100\frac{I_h}{I_1}$$

2.4.3 Frequency spectrum

By plotting the amplitude of each harmonic order on a graph, we obtain a graphical representation of the frequency spectrum. This technique is referred to as spectral analysis.

Figure 6 shows the spectral analysis of a square-wave signal.
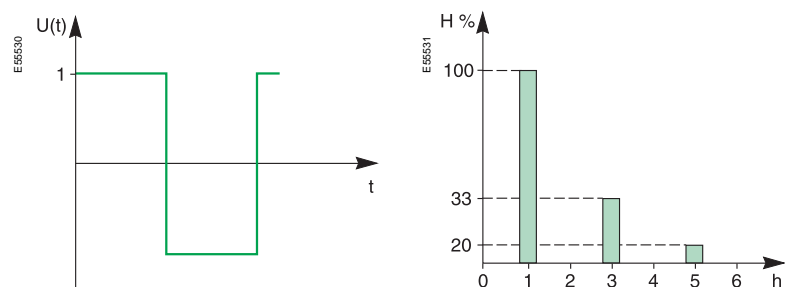
Figure 6 - *Spectral analysis of a square-wave signal, for voltage.*

2.4.4 RMS value

The rms value of a current or voltage is calculated on the basis of the rms values of the various harmonic orders:

$$I_{rms} = \sqrt{\sum_{h=1}^{\infty} I_h^2}$$

$$U_{rms} = \sqrt{\sum_{h=1}^{\infty} U_h^2}$$

THD stands for Total Harmonic Distortion.

The level of harmonic distortion is often used to define the degree of harmonic content in an alternating signal.

2.5 Total harmonic distorsion (THD)

2.5.1 Definition of total harmonic distortion

For a signal y, the total harmonic distortion (THD) is defined by the equation:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} y_h^2}}{y_1}$$

This definition complies with that of standard IEC 61000-2-2.

Note that the resulting value may exceed one.

According to the standard, h can generally be limited to 50. This equation produces a single value indicating the distortion of a voltage or a current flowing at a given point in a distribution system.

Harmonic distortion is generally expressed as a percentage.

2.5.2 Current and voltage THD

When dealing with current harmonics, the equation becomes:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1}$$

The above equation is equivalent to the one below, which is more direct and easier to use when the total rms value is known:

$$THD_I = \sqrt{\left(\frac{I_{rms}}{I_1}\right)^2 - 1}$$

When dealing with voltage harmonics, the equation becomes:

$$THD_u = \frac{\sqrt{\sum_{h=2}^{\infty} U_h^2}}{U_1}$$

2.5.3 particular case (thd)

In certain countries with different work habits, a different equation is used to determine harmonic distortion. In this equation, the value of the fundamental voltage U1 or the fundamental current I1 is replaced by the rms values U_{rms} and I_{rms} respectively.

To distinguish between the two equations, we will call the second the total harmonic factor (thd).

Example of a voltage thd:

$$thd_u = \frac{\sqrt{\sum_{h=2}^{\infty} U_h^2}}{U_{eff}}$$

The thd, whether for voltage or current, is always less than 100 %. It makes analogue measurements of signals easier but is used less and less because the result is very close to the THD defined above when a signal is not significantly distorted. What is more, it not well suited to highly distorted signals because it cannot exceed the value of 100 %, contrary to the THD defined at the beginning of this section.

The essential indicators of harmonic distortion and measurement principles

2.5.4 Relation between power factor and THD

When the voltage is sinusoidal or virtually sinusoidal, it may be said that:

$$P \# P_1 = U_1 . I_1 . \cos \varphi_1$$

Consequently: $\quad FP = \dfrac{P}{S} \# \dfrac{U_1 . I_1 . \cos \varphi_1}{U_1 . I_{rms}}$

Where as: $\quad \dfrac{I_1}{I_{rms}} = \dfrac{1}{\sqrt{1 + THD_I^2}}$

Hence: $\quad FP \# \dfrac{\cos \varphi_1}{\sqrt{1 + THD_I^2}}$

Figure 7 shows a graph of PF / cos φ as a function of THDi.
PF / cos φ = f (THDi).
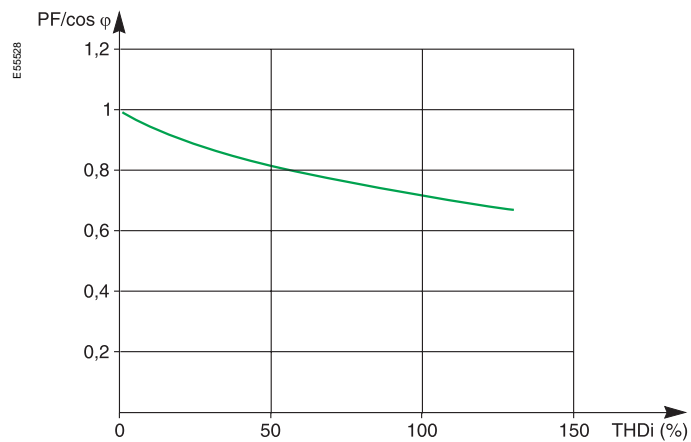
Figure 7 *- Variation of PF / cos φ as a function of THDi, where THDu = 0.*

2.6 Usefulness of the various indicators

■ **The voltage THD** indicates the distortion of the voltage wave.

The measured THDu can provide information on phenomena observed in the installation. A THDu value of less than 5 % is considered normal and there is virtually no risk of equipment malfunctions.

A THDu value between 5 % and 8 % indicates significant harmonic distortion. Some equipment malfunctions may occur.

A THDu value higher than 8 % indicates high harmonic distortion. Equipment malfunctions are probable. In-depth analysis is required and an attenuation system must be installed.

■ **The current THD** indicates the distortion of the current wave.

To identify the load causing the disturbance, the current THD must be measured on the incomer and the outgoers of the different circuits.

The measured THDi can provide information on phenomena observed in the installation. A THDi value of less than 10 % is considered normal and there is virtually no risk of equipment malfunctions.

A THDi value between 10 % and 50 % indicates significant harmonic distortion. Temperature rise may occur, which means cables and sources must be oversized.

A THDi value higher than 50 % indicates high harmonic distortion. Equipment malfunctions are probable. In-depth analysis is required and an attenuation system must be installed.

■ **The power factor** PF indicates the extent to which the source of the installation must be oversized.

■ **The crest factor** is used to determine the capacity of a generator (UPS or generator) to provide high instantaneous currents. For example, computers draw highly distorted current with crest factors that may reach 3 or even 5.

■ **The spectrum** (signal broken down into frequency) provides a different view of electrical signals and may be used to assess distortion.

Measuring the values
of the indicators

3.1 Measurement devices

3.1.1 Selection of a measurement device

Only **digital analysers**, based on recent technology, provide sufficiently accurate measurements for the indicators presented above.

Other measurement devices were used in the past.

■ **oscilloscopes** for observation purposes
A general indication of the distortion of a signal may be obtained by viewing the current or the voltage on an oscilloscope.
When the wave form is not sinusoidal, the signal is distorted by harmonics. The voltage and current peaks can be displayed.
Note that using an oscilloscope, it is not possible to precisely quantify the harmonic components.

■ **analogue spectral analysers**
Implementing old technology, these devices are made up of a passband filter combined with an rms voltmeter.
These devices, now outdated, produce mediocre results and do not provide any information on displacement.

3.1.2 Functions of digital analysers

The microprocessors used in digital analysers:

■ calculate the values of the harmonic indicators (**power factor, crest factor, distortion power, THD**)

■ offer a number of additional functions (correction, statistical detection, management of measurements, display, communication, etc.)

■ when they are multi-channel devices, provide simultaneously and nearly in real time the **spectral breakdown** of voltage and current.

3.1.3 Operating principle of digital analysers and data-processing techniques

Analogue signals are converted into a series of digital values.

On the basis of the digital values, an algorithm implementing the Fast Fourier Transform (FFT) calculates the amplitude and the phases of the harmonics over a large number of observation time windows.

Most digital analysers measure harmonics up to the 20th or 25th order for calculation of the THD.

Processing of the various values calculated using the FFT algorithm (smoothing, classification, statistics) can be carried out by the measurement device or by external software.

3.2 Procedure for harmonic analysis of a distribution system

Measurements are carried out on industrial and commercial sites as a:
■ preventive measure:
□ to obtain an **overall assessment of the extent of the problem** (map of the distribution system)
■ remedial measure:
□ to **determine the origin of a disturbance** and devise solutions to correct the problem
□ to **check that the solutions implemented actually produced the desired effect**.

Operating mode

Voltage and current measurements must be carried out:
■ at the power source
■ on the incoming busbars of the main distribution switchboard
■ on each of the outgoers leaving the main distribution switchboard.

When the measurements are carried out, it is necessary to have precise information on the conditions, in particular the status of capacitor banks (ON or OFF, number of stages connected).

On the basis of analysis results, it may be necessary to:
■ derate any future equipment installed
or
■ quantify the protection and harmonic-filtering solutions that must be installed
■ compare the values measured to the reference values of the utility (harmonic-distortion limits, acceptable values, reference values).

Use of measurement devices

The devices show both the instantaneous effects and the long-term effects of harmonics.
Correct analysis requires integrated values over time spans ranging from a few seconds to a few minutes, for observation periods of a few days.

The required values are:
■ the amplitude of voltage and current harmonics
■ the individual harmonic distortion of each order, for both current and voltage
■ total harmonic distortion for both current and voltage
■ where applicable, the displacement between voltage and current harmonics of the same order and the phase of the harmonics with respect to a common reference (the fundamental voltage, for example).

Measuring the values of the indicators

3.3 Anticipating harmonic conditioning needs

The harmonic indicators can be measured:
- by permanently installed devices
- by an expert present at least a half-day on the site (for a view limited in time).

3.3.1 The advantages of permanently installed devices

For a number of reasons, it is preferable to use devices installed permanently in the distribution system.

- a visit by an expert is necessarily limited in time, whereas measurements at different points in the installation over a sufficiently long period (one week to one month) **provide an overall view** of system operation and cover all the situations that may arise following:
  - fluctuation of the power source
  - variations in system operation
  - installation of new equipment

- measurement devices installed in the distribution system **prepare and facilitate troubleshooting** by experts, thus reducing the number and duration of their visits

- permanently installed measurement devices **detect any new disturbances** caused by the installation of new equipment, by new operating modes or by fluctuations on the distribution system.

3.3.2 The advantages of integrated measurement and detection devices

Measurement and detection devices that are built into the electrical distribution equipment offer a number of advantages.

- **for an overall assessment of the distribution system (preventive measure),** they avoid:
  - renting the measurement devices
  - hiring the services of experts
  - having to connect and disconnect all the measurement devices.

In an overall assessment of the distribution system, an analysis at the main low-voltage switchboard level can commonly be carried out by the incoming device and/or the measurement devices built into each outgoing device.

- **for an assessment in view of remedial action, they:**
  - indicate the operating conditions when the incident occurred
  - provide a "map" of the installation and indications on the selected solution.

A full diagnosis will often also require additional information provided by specific equipment suited to the problem at hand.

The main effects of harmonics in installations

4.1 Resonance

The use of both capacitive and inductive devices in distribution systems leads to resonance phenomena, resulting in extremely high or low impedance values. These variations in impedance modify the current and voltage in the distribution system.

Here we will discuss only parallel-resonance phenomena, which are the most frequent.

Consider the simplified diagram below, showing an installation made up of:
■ a transformer supplying power
■ linear loads
■ non-linear loads causing harmonic currents
■ power factor correction capacitors.
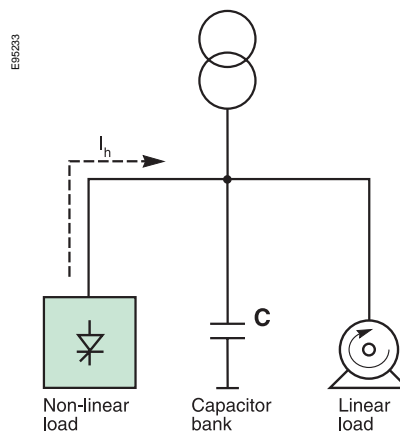
For harmonic-analysis purposes, the equivalent diagram is shown below:
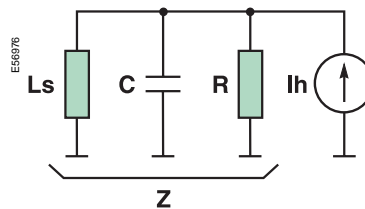
Ls: supply inductance (distribution system + transformer + line)
C: power factor correction capacitance
R: resistance of the linear loads
Ih: harmonic current

$$Z = \frac{jL_s\omega}{1 - L_s C\omega^2} \quad \text{when R is neglected.}$$

Resonance occurs when the denominator $1 - L_s C\omega^2$ approaches zero. The corresponding frequency is called the resonant frequency of the circuit. At this frequency, the impedance is at its maximum value, resulting in considerable voltage harmonics and consequently major voltage distortion. This voltage distortion is accompanied by the circulation of harmonic currents in the Ls + C circuit which are greater than the injected harmonic currents.

The distribution system and the power factor correction capacitors are subjected to considerable harmonic currents, resulting in the risk of overloads.

The main effects of harmonics in installations

4.2 Increased losses

4.2.1 Losses in conductors

The active power transmitted to a load depends on the fundamental current. When the current drawn by the load contains harmonics, the rms value of the current I_{rms} is greater than the fundamental I_1 .

With THD defined as:

$$THD = \sqrt{\left(\frac{I_{rms}}{I_1}\right)^2 - 1}$$

it may be deduced that:

$$I_{rms} = I_1 \sqrt{1 + THD^2}$$

Figure 8 below shows, as a function of the harmonic distortion:
- the increase in the rms current (I_{rms}) for a load drawing a given fundamental current
- the increase in the Joule losses (P_{Joules}), without taking into account the skin effect.

(The reference point for Irms and P$_{Joules}$ with no harmonics is set to 1 on the graph).
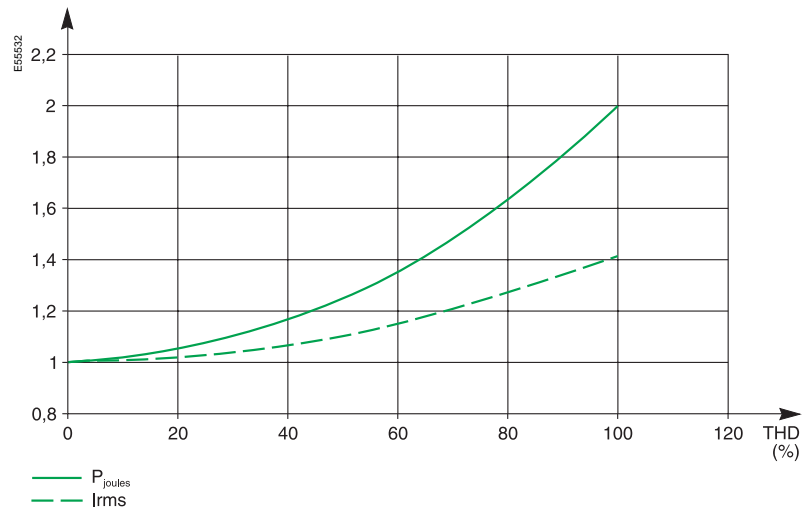
Figure 8 - *Increase in rms current and Joule losses as a function of THD.*

Current harmonics provoke an increase in Joule losses in all the conductors through which they flow and additional temperature rise in the transformers, circuit breakers, cables, etc.

4.2.2 Losses in asynchronous machines

Voltage harmonics, when applied to asynchronous machines, provoke the flow of currents with frequencies higher than 50 Hz in the rotor. These currents cause additional losses that are proportional to U_h^2/h.

■ estimating the losses:
□ a virtually square-wave supply voltage provokes a 20 % increase in losses
□ a supply voltage with the following levels of individual harmonic distortion (u_h) where U_1 is the fundamental voltage:
- u_5: 8 % of U_1
- u_7: 5 % of U_1
- u_{11}: 3 % of U_1
- u_{13}: 1 % of U_1
(i.e. a voltage THD of 10 %) results in additional losses of 6 %.

4.2.3 Losses in transformers

Harmonic currents flowing in transformers provoke increased losses in the windings through the Joule effect and increased iron losses due to eddy currents.

What is more, voltage harmonics cause iron losses due to hysterisis.

Roughly speaking, it may be said that the losses in the windings increase as the square of the current THD, and losses in the core increase linearly with the voltage THD.

■ estimating the losses:
□ the **increase in losses represents 10 % to 15 %** for public-distribution transformers, where distortion levels relatively low.

4.2.4 Losses in capacitors

Harmonic voltage, when applied to capacitors, provokes the flow of currents that are proportional to the frequency of the harmonics. These currents cause additional losses.

■ example:
consider a supply voltage with the following levels of individual harmonic distortion (u_h) where U_1 is the fundamental voltage:
- u_5: 8 % of U_1
- u_7: 5 % of U_1
- u_{11}: 3 % of U_1
- u_{13}: 1 % of U_1
(i.e. a voltage THD of 10 %).

$$I_1 = U_1.C.\omega$$

$$I_5 = U_5.C.5.\omega = u_5.5.I_1$$

$$I_7 = U_7.C.7.\omega = u_7.7.I_1$$

$$I_{11} = U_{11}.C.11.\omega = u_{11}.11.I_1$$

$$I_{13} = U_{13}.C.13.\omega = u_{13}.13.I_1$$

$$I_{rms} = \sqrt{\sum I_h^2}$$

$$\frac{I_{rms}}{I_1} = \sqrt{1 + (u_5.5)^2 + (u_7.7)^2 + (u_{11}.11)^2 + (u_{13}.13)^2} = 1{,}19$$

In this example, **Joule losses are multiplied by 1.19^2 = 1.4.**

The main effects of harmonics in installations

4.3 Overloads on installation equipment

4.3.1 Generators

Generators supplying non-linear loads must be derated due to the additional losses caused by the harmonic currents. The **derating coefficient is approximately 10 %** for a generator supplying a set of loads in which 30 % are non-linear loads. As a result, the generator must be oversized.

4.3.2 UPSs

The current drawn by computer equipment has a high crest factor. A UPS sized taking into account only the rms current value may not be capable of supplying the required peak current and thus be overloaded.

4.3.3 Transformers

■ the curve in figure 9 below shows typical derating values for a transformer supplying electronic (i.e. non-linear) loads.

Example: a **transformer supplying loads that are 40 %** electronic must be derated 40 %.
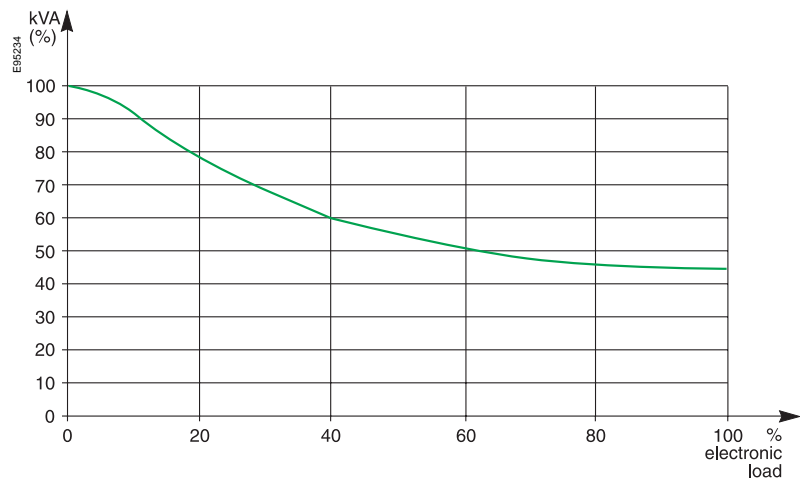
Figure 9 - *Derating values for a transformer supplying electronic loads.*

■ standard UTE C15-112 indicates a derating factor for transformers calculated as a function of the harmonic currents:

$$k = \cfrac{1}{\sqrt{1 + 0{,}1.\left(\sum_{h=2}^{40} h^{1,6}.T_h^2\right)}}$$

$$T_h = \frac{I_h}{I_1}$$

typical values:
□ "square-wave" current (spectrum inversely proportional to h [(1)]): k = 0.86
□ current drawn by a frequency converter (THD ≈ 50 %): k = 0.80.
(1) in fact, the current wave form is approximately that of a square wave form. This is the case for all current rectifiers (three-phase rectifiers, induction furnaces, etc.).

■ "K factor":
Standard ANSI C57.110 defines a derating method based on the "K factor", with the equation below.

$$K = \frac{\sum_{h=1}^{\infty} I_h^2.h^2}{\sum_{h=1}^{\infty} I_h^2} = \sum_{h=1}^{\infty} \left(\frac{I_h}{I_{rms}}\right)^2.h^2$$

The K factor produces more severe derating and is widely used in North America.

In the example presented below, the resulting "K factor" is 13.

Order h	I_h (%)
5	30
7	20
11	14
13	11
17	8
19	7
23	5
25	4

The increase in cost for a transformer sized using the "K factor" varies from 30 % to 60 % depending on the rating, in a range from 15 to 500 kVA.

4.3.4 Asynchronous machines

■ standard IEC 60892 defines a weighted harmonic voltage factor (*HVF*) for which the equation and the maximum permissible value are presented below:

$$HVF = \sum_{h=2}^{13} \frac{U_h\Delta}{h^2} \leq 0{,}02$$

■ example:
consider a supply voltage with the following levels of individual harmonic distortion (u_h) where U_1 is the fundamental voltage:
- u_3 : 2 % of U_1
- u_5 : 3 % of U_1
- u_7 : 1 % of U_1
(i.e. a voltage THD of 3.7 % and a HVF of 0.018).

In this example, the harmonic voltage factor is very close to the maximum value at which the machine must be derated.

Practically speaking, an asynchronous machine must not be supplied with power having a THDu greater than 10 %.

The main effects of harmonics in installations

4.3.5 Capacitors

According to standards, the rms current flowing in capacitors must not exceed 1.3 times the rated current.

■ example (already presented above):
consider a supply voltage with the following levels of individual harmonic distortion (u_h) where U_1 is the fundamental voltage:
- u_5 : 8 % of U_1
- u_7 : 5 % of U_1
- u_{11} : 3 % of U_1
- u_{13} : 1 % of U_1
(i.e. a voltage THD of 10 %).

as a result $\dfrac{I_{rms}}{I_1} = 1,19$, at the rated voltage.

At a voltage level equal to 1.1 times the rated voltage, $\dfrac{I_{rms}}{I_1} = 1,3$ the maximum

current level is overrun and the capacitors must be resized.

4.3.6 Neutral conductors

Consider a system made up of a balanced three-phase source and three identical single-phase loads connected phase-to-neutral.
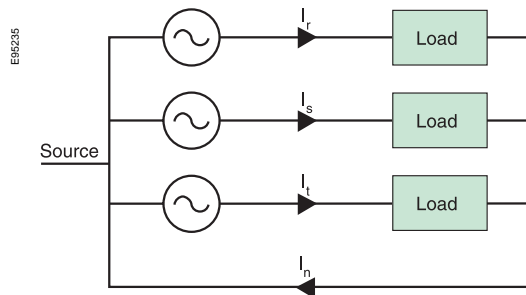
Figure 10 - *Flow of currents in the various conductors connected to a three-phase source.*

The graphs in figure 11 below show an example of the currents flowing in the three phases and the resulting current in the neutral conductor.
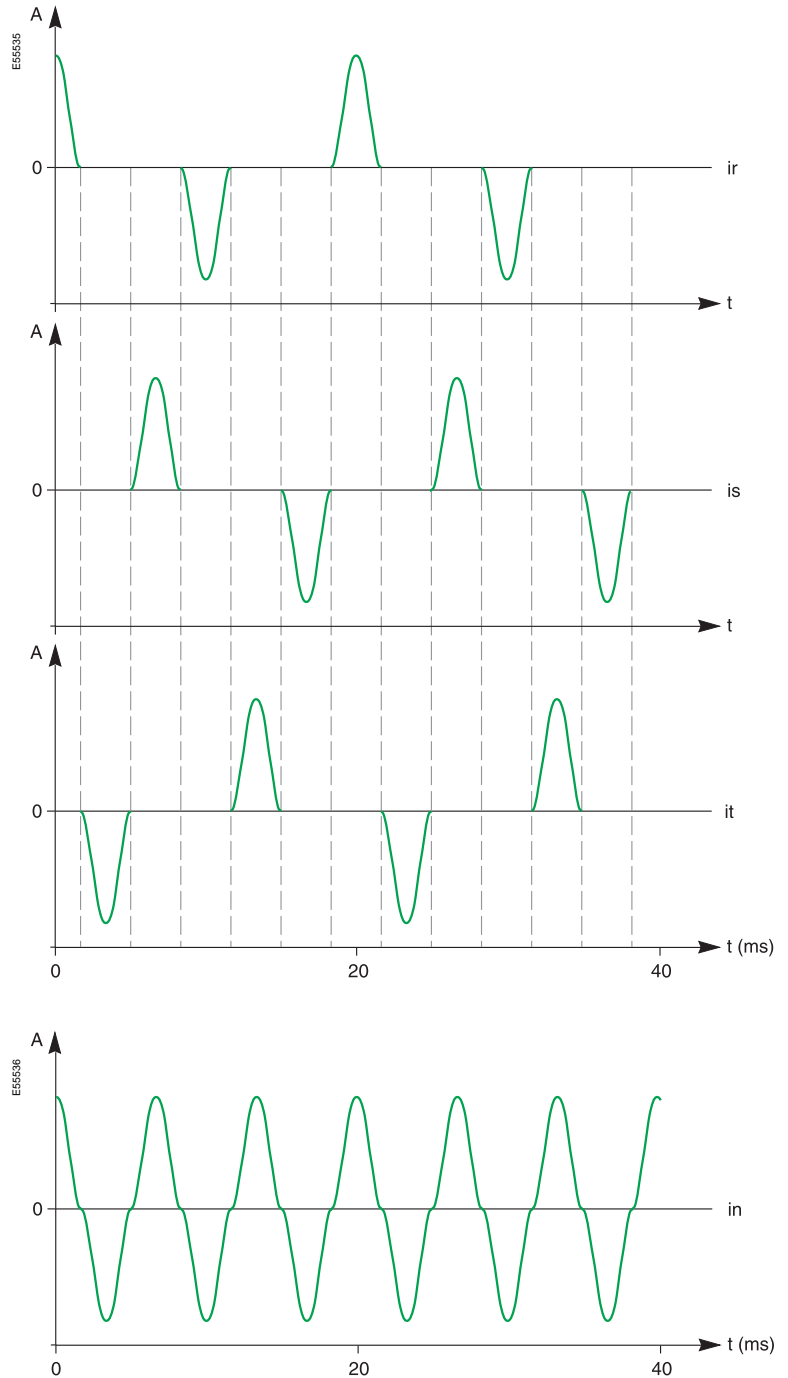
Figure 11 - *Example of currents flowing in the various conductors connected to a three-phase load, where $I_n = i_r + i_s + i_t$.*

In this example, the rms value of the current in the neutral conductor is $\sqrt{3}$ times greater than that of the current in a phase. The neutral conductor must therefore be resized accordingly.

The main effects of harmonics in installations

4.4 Disturbances to sensitive loads

4.4.1 Effects of supply-voltage distortion

■ distortion of the supply voltage may disturb operation of sensitive loads, including:
□ regulation systems (temperature, etc.)
□ computer equipment
□ control and monitoring systems (protection relays).

4.4.2 Disturbances on telephone lines

Harmonics can induce disturbances in circuits conducting low currents. The degree of disturbance depends on the distance over which the power and signal lines run in parallel, the distance between the lines and the frequency of the harmonics.

4.5 Economic consequences

4.5.1 Power losses

The Joule effect, induced by harmonic currents in the conductors and equipment, causes additional power losses.

4.5.2 Additional subscribed power costs

The presence of harmonic currents makes it necessary to increase the subscribed power level and, consequently, the cost of the subscription.

What is more, utilities will be increasingly inclined in the future to transfer costs to the producers of harmonic disturbances.

4.5.3 Oversizing of equipment

■ derating of power sources (generators, transformers and UPSs) means they must be oversized

■ conductors must be sized taking into account the flow of harmonic currents. Because the frequencies of the harmonics are higher than that of the fundamental, the impedances encountered by these currents are higher. To avoid excessive losses due to the Joule effect, the conductors must be oversized

■ the circulation of harmonic currents in the neutral conductor means the conductor must be oversized.

4.5.4 Reduction in the service life of equipment

(Data obtained from the Canadian Electrical Association).

When distortion of the supply voltage is in the 10 % range, equipment service life is significantly reduced. Depending on the type of device, the reduction in service life may be estimated at:
- 32.5 % for single-phase machines
- 18 % for three-phase machines
- 5 % for transformers.

To maintain the service life observed with a normal supply voltage, devices must be oversized.

4.5.5 Nuisance tripping and installation shutdown

Installation circuit breakers are subjected to current peaks caused by harmonics.

These current peaks cause nuisance tripping and result in production losses as well as costs corresponding to the time required to put the installation back into running order.

4.5.6 A few examples

For the installations in the examples below, the significant economic consequences made necessary the use of harmonic filters.

- computer centre of an insurance company:
in this computer centre, nuisance tripping of a circuit breaker caused a loss estimated at 100 000 euros per hour of down time

- pharmaceutical laboratory:
harmonics provoked the failure of an engine generator set and interruption of a very lengthy test phase on a new product. The estimated loss amounted to 17 million euros

- metallurgy factory:
induction furnaces provoked overloads causing irreversible damage to three transformers ranging from 1500 to 2500 kVA in one year, and production losses estimated at 20 000 euros per hour

- garden-furniture factory:
failure of variable-speed drives provoked production losses estimated at 10 000 euros per hour.

Standards and the regulatory environment

In order to rapidly reduce the effects of harmonic disturbances, a three-part system of standards and regulations is now in force. This system is presented below.

Harmonic levels are governed by a series of standards and regulations:
■ compatibility standards for distribution systems
■ standards setting limit values for devices causing harmonics
■ recommendations issued by utilities and applicable to installations.

5.1 Compatibility standards between distribution systems and products

These standards stipulate a number of criteria concerning compatibility between distribution systems and products, such that:
■ the harmonic disturbances caused by a device in the system must not exceed the set limits
■ each device must be capable of operating normally in the presence of disturbances at least equal to the set limits

■ IEC 1000-2-2 for low-voltage public distribution systems
■ IEC 1000-2-4 for low-voltage and medium-voltage industrial installations.

5.2 Distribution-system quality standards

■ standard EN 50160 stipulates the characteristics of the voltage supplied by low-voltage public distribution systems
■ standard IEEE 519 (Recommended practices for harmonic control in electrical power systems) is a joint approach between utilities and their customers to limit the impact of non-linear loads.
What is more, utilities encourage preventive action to limit the impact on the quality of electricity, temperature rise and reductions in the power factor. They are also considering applying financial penalties to those customers producing disturbances.

5.3 Standards on devices

■ IEC 61000-3-2 ou EN 61000-3-2 for low-voltage devices drawing less than 16 A
■ IEC 61000-3-4 or EN 61000-3-4 for low-voltage devices drawing more than 16 A.

5.4 Maximum permissible harmonic values

On the basis of data drawn from a number of international studies, it was possible to estimate the typical harmonic values encountered in distribution systems.

Formulated on the basis of work carried out by the CIGRE organisation, the table below reflects the opinion of a large number of utilities concerning harmonic limits that should not be exceeded.

Odd harmonics, non-multiples of 3				Odd harmonics, multiples of 3				Even harmonics			
Order h	LV	MV	VHV	Order h	LV	MV	VHV	Order h	LV	MV	VHV
5	6	6	2	3	5	2.5	1.5	2	2	1.5	1.5
7	5	5	2	9	1.5	1.5	1	4	1	1	1
11	3.5	3.5	1.5	15	0.3	0.3	0.3	6	0.5	0.5	0.5
13	3	3	1.5	21	0.2	0.2	0.2	8	0.5	0.2	0.2
17	2	2	1	> 21	0.2	0.2	0.2	10	0.5	0.2	0.2
19	1.5	1.5	1					12	0.2	0.2	0.2
23	1.5	1	0.7					> 12	0.2	0.2	0.2
25	1.5	1	0.7								
> 25	0.2 + 25h	0.2 + 25h	0.1 + 25h								

5.5 Installation standards

The impact of the THD value on the safety of equipement has led the installation standards to impose thresholds in determining their capacity to be detrimental. Therefore the French installation standard NF C 15-100 imposes the choice of neutral conductors cross section according to the thresholds of 15 %, 33 % and 45 % of the level of rank 3 harmonics in the phase current (§ 524.2):

	THDI$_{H3}$ ≤ 15 %	15 % < THDI$_{H3}$ ≤ 33 %	THDI$_{H3}$ > 33 %
S$_N$ = 1/2 S$_{Ph}$	Permitted Neutral protection compulsory	Prohibited	Prohibited
S$_N$ = S$_{Ph}$	Permitted Neutral protection optional	Permitted Current in the phases determines the cross section of all conductors	Permitted The current in the neutral determines the cross section of all the conductors
S$_N$ > S$_{Ph}$			Permitted The current in the neutral only determines the cross section of the neutral

In this case, Schneider Electric proposes special trip units (OSN trip units) which allow using a cross section of phase conductors smaller than the neutral conductor cross section, in the case of large THDI$_{H3}$.

Harmonic three in the phase current (%)	Reduction factor	
	Choice based on the phase current	Choice based on the neutral current
0 - 15	1.0	-
15 - 33	0.86	-
33 - 45	-	0.86
> 45	-	1.0

Solutions to attenuate harmonics

En bref

There are three different types of solutions that may be used to attenuate the effects of harmonics:
■ modifications to the installation
■ use of special devices in the power supply system (inductors, special transformers)
■ filters.

6.1 General solutions

To limit the propagation of harmonics in the distribution system, a number of measures may be taken, particularly when designing a new installation.

6.1.1 Positioning the disturbing loads upstream in the system

The overall level of harmonic disturbance increases as the short-circuit power decreases.

Economic considerations aside, it is therefore preferable to connect the disturbing loads as far upstream as possible (see figure 12a).
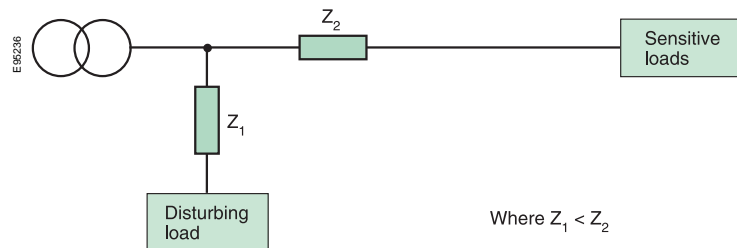
Figure 12a - *Supply of non-linear loads as far upstream as possible (recommended diagram).*

6.1.2 Grouping the disturbing loads

When preparing the single-line diagram, separate where possible the disturbing equipment from the other loads (see figure 12b). Practically speaking, the different types of loads should be supplied by different busbars.

By grouping the disturbing loads, the possibilities of angular recomposition are increased. The reason is that the vector sum of the harmonic currents is lower than their algebraic sum.

An effort should also be made to avoid the flow of harmonic currents in the cables, thus limiting voltage drops and temperature rise in the cables.
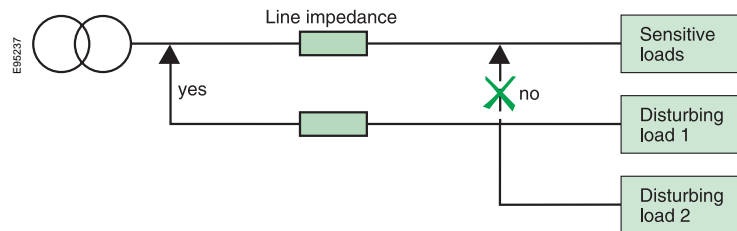
Figure 12b - *Grouping of non-linear loads and supply as far upstream as possible (recommended diagram).*

6.1.3 Separating the sources

In efforts to attenuate harmonics, an additional improvement may be obtained by supplying the different loads via different transformers, as indicated in the simplified diagram below (figure 13).
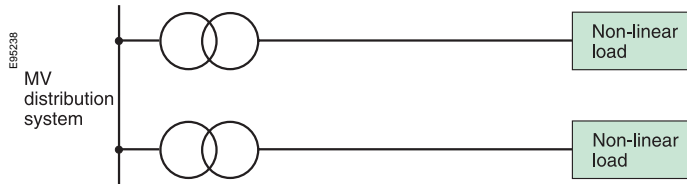
Figure 13 - *Supply of the disturbing loads via a separate transformer.*

This disadvantage of this solution is the increase in the cost of the installation.

6.1.4 Using transformers with special connections

Special types of connection may be used in transformers to eliminate certain harmonic orders.

The harmonic orders eliminated depend on the type of connection implemented:
■ a delta-star-delta connection eliminates harmonic orders 5 and 7 (see figure 14)
■ a delta-star connection eliminates harmonic order 3 (the harmonics flow in each of the phases and loop back via the transformer neutral)
■ a delta-zigzag$_5$ connection eliminates harmonic order 5 (loop back via the magnetic circuit).
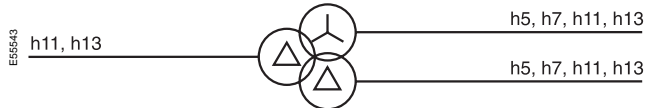
Figure 14 - *A delta-star-delta transformer prevents propagation of harmonic orders 5 and 7 upstream in the distribution system.*

6.1.5 Installing inductors

In installations comprising variable-speed drives, the current can be smoothed by installing **line inductors**. By increasing the impedance of the supply circuit, the harmonic current is limited.

Use of **harmonic inductors** on capacitor banks is a means of increasing the impedance of the inductor and capacitor assembly, for harmonics with high frequencies.

Solutions to attenuate harmonics

6.1.6 Selection of a suitable system earthing arrangement

■ TNC system

In TNC systems, a single conductor, the PEN, ensures protection in the event of an earth fault and carries imbalance currents.

Under steady-state conditions, the harmonic currents flow through the PEN. However, the PEN has a certain impedance, resulting in slight voltage differences (a few volts) between devices which may lead to malfunctions of electronic equipment.

The TNC system must therefore be used only for the supply of power circuits on the upstream end of installations **and must never be used for the supply of sensitive loads**

■ TNS system

This system is recommended when harmonics are present.

The neutral conductor and the protection conductor PE are completely separate, thus ensuring a much more stable voltage on the distribution system.

In cases where the preventive measures presented above are not sufficient, the installation must be equipped with filters.

There are three types of filters:
■ passive filters
■ active filters
■ hybrid filters.

6.2 Solutions when limit values are exceeded

6.2.1 Passive filters

■ typical applications:
□ industrial installations comprising a set of devices causing harmonics with a total power rating greater than approximately 200 kVA (variable-speed drives, UPSs, rectifiers, etc.)
□ installations where power factor correction is required
□ situations where voltage distortion must be reduced to avoid disturbing sensitive loads
□ situations where current distortion must be reduced to avoid overloads

■ operating principle:
an LC circuit, tuned to each of the harmonic frequencies requiring filtering, is installed in parallel with the device causing the harmonic distortion (see figure 15).
This bypass circuit draws the harmonics, thus avoiding the flow of harmonics to the power source.
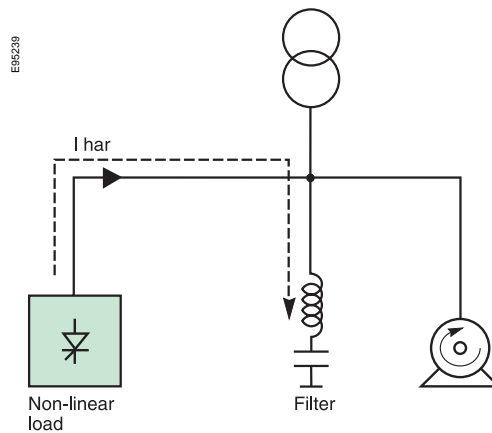
Figure 15 - *Operating principle of a passive filter.*

Generally speaking, the passive filter is tuned to a harmonic order near the one to be eliminated. A number of parallel-connected filters may be used when a significant reduction in distortion over a range of orders is required.

6.2.2 Active filters (active harmonic conditioners)

■ typical applications:
□ commercial installations comprising a set of devices causing harmonics with a total power rating less than 200 kVA (variable-speed drives, UPSs, office equipment, etc.)
□ situations where current distortion must be reduced to avoid overloads

■ operating principle:
active filters are systems employing power electronics, installed in series or in parallel with the non-linear load, to provide the harmonic currents required by non-linear loads and thereby avoid distortion on the power system.

Solutions to attenuate harmonics

Figure 16 shows an example of an active filter compensating the harmonic current ($I_{har} = -I_{act}$).
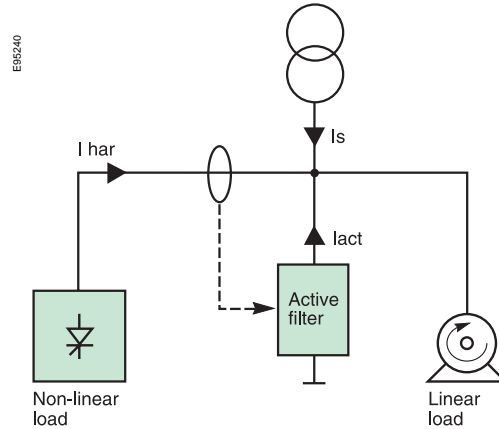
Figure 16 *- Operating principle of an active filter.*

The active filter injects, in opposite phase, the harmonics drawn by the load, such that the line current Is remains sinusoidal.

6.2.3 Hybrid filters

■ typical applications:
□ industrial installations comprising a set of devices causing harmonics with a total power rating greater than 200 kVA approximately (variable-speed drives, UPSs, rectifiers, etc.)
□ installations where power factor correction is required
□ situations where voltage distortion must be reduced to avoid disturbing sensitive loads
□ situations where current distortion must be reduced to avoid overloads
□ situations where conformity with strict harmonic-emission limits is required

■ operating principle:
the two types of filters presented above can be combined in a single device, thus constituting a hybrid filter (see figure 17). This new filtering solution combines the advantages of the existing systems and provides a high-performance solution covering a wide power range.
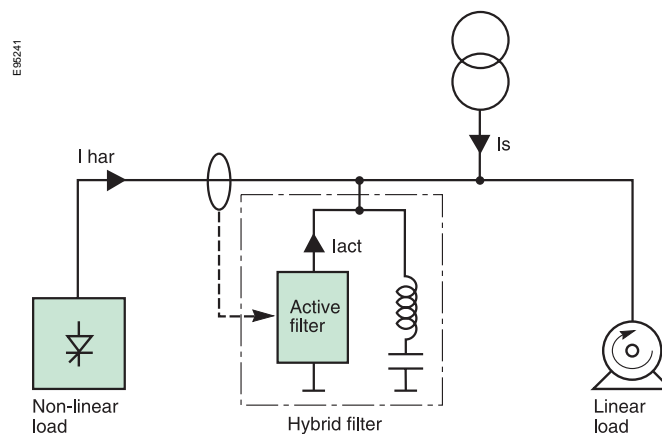
Figure 17 *- Operating principle of a hybrid filter.*

6.2.4 Selection criteria

■ **passive filters** offer both:
□ power factor correction
□ large capacity for current filtering.

Installations where passive filters are installed must be sufficiently stable, i.e. a low level of load fluctuations.

If a high level of reactive power is supplied, it is advised to de-energise the passive filter when load levels are low.

Preliminary studies for a filter must take into account any capacitor banks and may lead to their elimination.

■ **active harmonic** conditioners compensate harmonics over a wide range of frequencies. They can adapt to any load, however, their conditioning capacity is limited

■ **hybrid filters** combine the strong points of both passive filters and active harmonic conditioners.

Harmonic-detection devices from Schneider Electric

Power Meter PM800.

Circuit Monitor Series 3000.

Micrologic H control unit integrated into the NW and NT Masterpact circuit breakers.
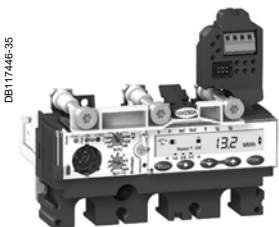
Micrologic E trip unit integrated into Compact NSX circuit breakers.

7.1 Detection

Harmonic pollution control mainly requires measurement. According to each installation various kinds of Schneider Electric equipment provide a solution.

7.1.1 Built-in power meters

Micrologic: a power meter built into circuit breakers

The Micrologic control unit equips Masterpact power circuit breakers (Micrologic H) and Compact NSX moulded case circuit breakers (Micrologic 5/6 A/E).

The Micrologic control unit provides in-depth analysis of power quality and detailed diagnosis of events. The data provided by Micrologic is intended for use on a switchboard display unit or a supervisor.

It provides:
■ measurement of currents, voltages, active and reactive power
■ measurement of the current and voltage THD
■ display of the current and voltage harmonic components (amplitude and phase up to the 31th order)
■ recording of wave forms (waveform capture).

A switchboard display (FDM 121) allows us to increase display and reading ergonomics of electrical parameters.

7.1.2 External power meters

Power Meter and Circuit Monitor of PowerLogic System

Powerlogic products are high-performance analysis tools for medium- and low voltage distribution systems. They are digital power meters designed to measure power quality.

The Powerlogic range is made up of Power Meters (PM), Circuit Monitors (CM) and ION devices. This highly modular range provides solutions for very simple needs, covered by the PMs, up to the most complex, covered by the CMs. These products are used in new or existing installations where a high level of power quality is mandatory. They may be operated both locally and remotely.

Depending on their position in the installation, Power Meters offer an initial estimation of power quality. The main measurements carried out by PMs are the:
■ current and voltage THD
■ power factor.

Depending on the model in the range, these functions may be combined with timestamping and alarms.

CM and PM850 provide in-depth analysis of power quality and system disturbances. The main CM functions are:
■ measurement of over 100 electrical parameters
■ storage in memory and time stamping of the minimum and maximum values for each electrical parameter
■ alarm tripping by electrical parameters
■ event logging
■ recording of current and voltage disturbances
■ harmonic analysis
■ recording of wave forms (waveform capture)
■ standard EN50160 indicators (CM4000 and 4000T only).
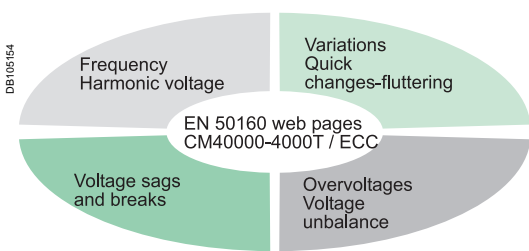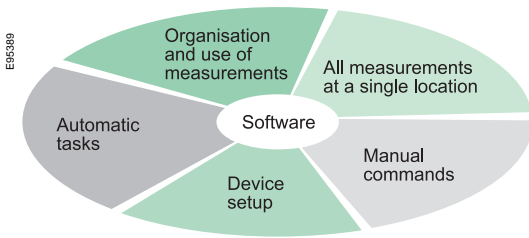
7.1.3 Using power-meter data

Remote management and analysis software

In the wider framework of an entire distribution system that must be monitored, Schneider Electric offers the communications systems required to interconnect all the various devices via a network, thus making it possible to centralise information and obtain an overall view of disturbances over the entire distribution system.

Depending on the devices and software used, it is possible to carry out measurements in real time, calculate averages, record wave forms, anticipate on alarms, etc.

The power meters transmit all the accessible data via ModBus.

The primary purpose of these systems is to assist in identifying and planning maintenance work. They can significantly reduce servicing times and installation costs for temporary devices used for on-site measurements or for sizing of equipment (filters).

Schneider Electric offers one supervision-software product and Web pages.

SMS

SMS is a very complete software system for analysis of distribution systems, used in conjunction with Powerlogic products.

Installed on a standard PC, it can be used to:
■ view measurements on a real time basis
■ view histories, over a set period
■ select the manner in which data is displayed (tables, various curves)
■ process statistical data (display of histograms).

Web pages (EN 50160) for CM 4000-4000 T only, with ECC Card.

HTML format summarising and diagnosis pages concerning standard EN 50160 indicators can be downloaded on the Ethernet ECC card,to use all these data directly with a standard Web application (e.g. Internet Explorer).

7.2 Selection guide

The table below presents the most suitable applications of the various devices for harmonic measurements:

Goal of detection	PM500 to PM820	Micrologic E	Micrologic H	PM850/CM3000/4000
Overall evaluation of distribution-system status	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■
Precise diagnosis	■ ■	■ ■	■ ■ ■	■ ■ ■
Analysis	■	■ ■	■ ■	■ ■ ■
Advantages	Basic measurements, easy to use, inexpensive, small size and high accuracy	Built into the moulded-case circuit breaker, allows monitoring of installation and provides measurement of more than 100 electrical parameters without external CT.	Built into the circuit-breaker, allows monitoring at the supply end of the installation or on large feeders without additional cabling or CT + on-board non volatile alarm.	Very complete, highly accurate measurement device, large data-storage capacity, programmable fast measurements

Key:
■ ■ ■ : perfectly suited
■ ■ : satisfactory
■ : Manque légende
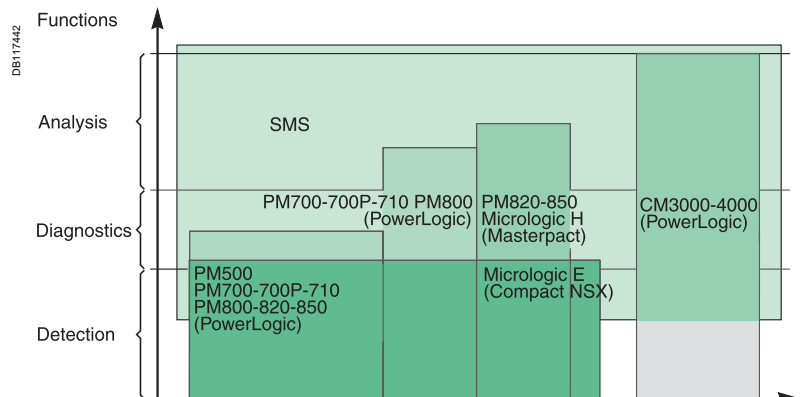
Figure 18 - *Relative positions of the various detection products.*

Product selection according to measurement functions

Power Meter

		PM9P/PM9C	PM500	PM700	PM700P	PM710	PM810	PM820	PM850
General selection criteria									
Installation		On DIN rail	Flush mount	Flush mount			Flush mount		
Use on LV distribution systems		■	■	■	■	■	■	■	■
Use on LV and HV distribution systems		-	■	■	■	■	■	■	■
Current / voltage accuracy		0.5 %	0.5 %	0.5 %	0.5 %	0.5 %	0.1 %	0.1 %	0.1 %
Power / energy accuracy		2 %	1 %	1 %	1 %	1 %	1 %	0.5 %	0.5 %
Instantaneous rms values									
Current	■ Phases	■	■	■	■	■	■	■	■
	■ Neutral	■	■	■	■	■	■	■	■
	■ Extended measurement range	-	-	-	-	-	-	-	-
Voltage	Phase-to-phase and phase-to-neutral	■	■	■	■	■	■	■	■
Frequency		■	■	■	■	■	■	■	■
Total power	■ Active	■	■	■	■	■	■	■	■
	■ Reactive	■	■	■	■	■	■	■	■
	■ Apparent	■	■	■	■	■	■	■	■
Power per phase	■ Active	■	■	■	■	■	■	■	■
	■ Reactive	■	■	■	■	■	■	■	■
	■ Apparent	-	■	■	■	■	■	■	■
Power factor	■ Total	■	■	■	■	■	■	■	■
	■ Per phase	-	■	-	-	-	■	■	■
Energy values									
Active energy		■	■	■	■	■	■	■	■
Reactive energy		■	■	■	■	■	■	■	■
Apparent energy		-	■	■	■	■	■	■	■
User-set accumulation mode		-	-	-	-	-	■	■	■
Demand values									
Current	Present and maximum values	-	■	■	■	■	■	■	■
Total active power	Present and maximum values	■	■	■	■	■	■	■	■
Total reactive power	Present and maximum values	-	■	■	■	■	■	■	■
Total apparent power	Present and maximum values	-	■	■	■	■	■	■	■
Total predicted demand	kW, kVAR, kVA	-	-	-	-	-	■	■	■
Synchronisation of calculation window		-	Option	-	-	-	■	■	■
User-set calculation mode		-	-	■	■	■	■	■	■
Power quality measurements									
Total harmonic distortion	■ Voltage	-	■	■	■	■	■	■	■
	■ Current	-	■	■	■	■	■	■	■
Individual harmonic content		-	-	-	-	-	-	■	■
Waveform capture		-	-	-	-	-	-	-	■
Detection of voltage sags and swells		-	-	-	-	-	-	-	-
Programmable (logic and mathematical functions)		-	-	-	-	-	-	-	-
Detection and capture of transients (< 1 µs)		-	-	-	-	-	-	-	-
Flicker		-	-	-	-	-	-	-	-
EN50160 compliance checking		-	-	-	-	-	-	-	-
True rms measurement	Maximum harmonic number	15	31	15	15	15	63	63	63
Sampling rate	Points per cycle	-	-	32	32	32	128	128	128

(1) Measurement sensors included.

	Circuit Monitor					Micrologic control units for low-voltage circuit breakers				
	CM3250	CM3350	CM4000	CM4000XR	CM4000T	A	P	H	5/6 A	5/6 E
	Display in front and module on DIN rail		Display in front and module inside switchboard			Integrated in the circuit breaker			Integrated	Integrated
	■	■	■	■	■	■	■	■	■	■
	■	■	■	■	■	-	-	-	-	-
	0.1 %	0.1 %	0.07 %	0.07 %	0.07 %	1.5 % (1)	1.5 % (1)	1.5 % (1)	1 % (1)	1 % / 0.5 % (1)
	0.5 %	0.5 %	0.2 %	0.5 %	0.2 %	-	2.0 % (1)	2.0 % (1)	-	2 % (1)
	■	■	■	■	■	■	■	■	■	■
	■	■	■	■	■	■	■	■	■	■
	-	-	-	■	-	■	■	■	■	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	■	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	-	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	■	■	-	■
	■	■	■	■	■	-	-	■	-	■
	■	■	■	■	■	-	-	■	-	■
	■	■	■	■	■	-	-	■	-	-
	■	■	■	■	■	-	-	■	-	-
	-	■	■	■	■	-	-	-	-	-
	-	-	■	■	■	-	-	-	-	-
	-	-	-	-	■	-	-	-	-	-
	-	-	-	-	■	-	-	-	-	-
	■	■	■	■	■	-	-	-	-	-
	63	63	255	255	255	12	31	31	15	15
	128	128	512	512	83 333	24	64	64	40	40

Product selection according to measurement functions

	Power Meter							
	PM9P/PM9C	PM500	PM700	PM700P	PM710	PM810	PM820	PM850
Logging								
Min/max of instantaneous values	-	Option	■	■	■	■	■	■
Data logging	-	-	-	-	-	-	2	4
Event logging	-	-	-	-	-	-	■	■
Trend curves	-	-	-	-	-	-	-	■
Alarms	-	Option	-	-	-	■	■	■
Alarm notification via email	-	-	-	-	-	-	-	-
Sequence of Events Recording	-	-	-	-	-	-	-	-
Date and time stamping	-	-	-	-	-	■	■	■
GPS time synchronisation	-	-	-	-	-	-	-	-
Storage capacity	-	-	-	-	-	-	80 Ko	800 Ko
Display, sensors, input/outputs								
Front-panel display	■	■	■	■	■	■	■	■
Built-in current and voltage sensors	-	-	-	-	-	-	-	-
Pulse output	1 (PM9P)	Option	-	2	-	1	1	1
Digital or analogue inputs (max. number)	-	3	-	-	-	13	13	13
Digital or analogue outputs (max. number including pulse outputs)	1 (PM9P)	5	-	2	-	9	9	9
Direct voltage connections without external VT	450 V	480 V	480 V	480 V	480 V	600 V	600 V	600 V
Power supply								
AC/DC version — AC	230 V	110 to 400 V	110 to 415 V			110 to 415 V		
AC/DC version — DC	-	120 to 350 V	125 to 250 V			125 to 250 V		
DC version	24 to 48 V	24 to 48 V	-			-		
Communication								
RS 485 port	■ (PM9C)	Option	-	-	■	■	■	■
Infra-red port	-	-	-	-	-	-	-	-
RS 232 port	-	-	-	-	-	-	-	-
Modbus	■	■	-	-	■	■	■	■
Ethernet port (Modbus/TCP/IP protocol)	-	-	-	-	-	-	-	-
HTML Web-page server	-	-	-	-	-	-	-	-
Ethernet gateway for other products on an RS 485 link	-	-	-	-	-	-	-	-

(2) Maximum only.
(3) The total number of inputs and outputs may not exceed 25.
(4) Self-powered.
(5) Available with EGX400 and MPS100 gateway.

Circuit Monitor					Micrologic control units for low-voltage circuit breakers				
CM3250	CM3350	CM4000	CM4000XR	CM4000T	A	P	H	5/6 A	5/6 E
■	■	■	■	■	■ (2)	■	■	■	■
14	14	14	14	14	-	-	-	-	-
■	■	■	■	■	-	■	■	■	■
■	■	■	■	■	-	-	-	-	-
■	■	■	■	■	-	■	■	■	■
Option	Option	Option	Option	Option	-	-	-	(5)	(5)
■	■	■	■	■	-	-	-	-	-
■	■	■	■	■	-	■	■	■	■
Option	Option	Option	Option	Option	-	-	-	-	-
Up to 8 Mo	Up to 8 Mo	Up to 32 Mo	Up to 32 Mo	Up to 32 Mo	-	-	-	-	-
Option	Option	Option	Option	Option	■	■	■	■	■
-	-	-	-	-	■	■	■	■	■
1	1	1	1	1	-	-	-	-	-
4	4	16 (3)	16 (3)	16 (3)	-	-	-	-	-
5	5	17 (3)	17 (3)	17 (3)	6	6	6	2	1
600 V	600 V	600 V	600 V	600 V	690 V	690 V	690 V	690 V	690 V
100 to 275 V		100 to 275 V			(4)	(4)	(4)	(4)	(4)
125 to 250 V		125 to 250 V			(4)	(4)	(4)	(4)	(4)
-		-			(4)	(4)	(4)	Option	Option
■	■	■	■	■	Option	Option	Option	Option	Option
Option	Option	Option	Option	Option	-	-	-	-	-
-	-	■	■	■	-	-	-	-	-
■	■	■	■	■	■	■	■	■	■
Option	Option	Option	Option	Option	-	-	-	-	-
Option	Option	Option	Option	Option	-	-	-	(5)	(5)
Option	Option	Option	Option	Option	-	-	-	-	-

Product selection according to measurement functions

		ION8800			ION8600		
		A	B	C	A	B	C
General selection criteria							
Installation		DIN 43862 rack			Flush mount		
Use on LV distribution systems		■	■	■	■	■	■
Use on LV and HV distribution systems		-	■	■	■	■	■
Current / voltage accuracy		0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %
Power / energy accuracy		0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %
Instantaneous rms values							
Current	■ Phases	■	■	■	■	■	■
	■ Neutral	■	■	■	■	■	■
	■ Extended measurement range	-	-	-	-	-	-
Voltage	Simple et composée	■	■	■	■	■	■
Frequency		■	■	■	■	■	■
Total power	■ Active	■	■	■	■	■	■
	■ Reactive	■	■	■	■	■	■
	■ Apparent	■	■	■	■	■	■
Power per phase	■ Active	■	■	■	■	■	■
	■ Reactive	■	■	■	■	■	■
	■ Apparent	-	■	■	■	■	■
Power factor	■ Total	■	■	■	■	■	■
	■ Per phase	■	■	■	■	■	■
Energy values							
Active energy		■	■	■	■	■	■
Reactive energy		■	■	■	■	■	■
Apparent energy		■	■	■	■	■	■
User-set accumulation mode		■	■	■	■	■	■
Demand values							
Current	Present and maximum values	■	■	■	■	■	■
Total active power	Present and maximum values	■	■	■	■	■	■
Total reactive power	Present and maximum values	■	■	■	■	■	■
Total apparent power	Present and maximum values	■	■	■	■	■	■
Total predicted demand	kW, kVAR, kVA	■	■	■	■	■	■
Synchronisation of calculation window		■	■	■	■	■	■
User-set calculation mode		■	■	■	■	■	■
Power quality measurements							
Interharmonicc		■	■	-	■	-	-
Total harmonic distortion	■ Voltage	■	■	■	■	■	■
	■ Current	■	■	■	■	■	■
Individual harmonic content (current and voltage)		■	■	■	■	■	■
Waveform capture		■	-	-	■	-	-
Detection of voltage sags and swells		■	■	■	■	■	■
Programmable (logic and mathematical functions)		■	■	■	■	■	■
Detection and capture of transients (< 1 μs)		■	-	-	■	-	-
Flicker		■	■	-	■	-	-
EN50160 compliance checking		■	■	-	■	-	-
True rms measurement	Maximum harmonic number	63	63	63	63	63	31
Sampling rate	Points per cycle	1024	1024	1024	256	256	256

ION7650	ION7550	ION7350	ION7330	ION7300	ION6200
Display in front and module on DIN rail		Display in front and module inside switchboard			
■	■	■	■	■	■
■	■	■	■	■	■
0.1 %	0.1 %	0.25 %			0.3 %
0.20 %	0.20 %	1.5 %	1.5 %	1.5 %	0.50 %
■	■	■	■	■	■
■	■	■	■	■	■
■	■	-	-	-	-
■	■	■	■	■	■
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	-	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	■
■	■	■	■	■	-
■	■	■	■	■	-
■	-	-	-	-	-
■	■	■	■	■	Option
■	■	■	■	■	Option
■	■	■	■	■	-
■	-	■	-	-	-
■	■	■	-	-	-
■	■	■	■		-
■	-	-	-	-	-
■	-	-	-	-	-
■	-	-	-	-	-
63	63	31	15	15	-
1024	256	64	32	32	64

Product selection according to measurement functions

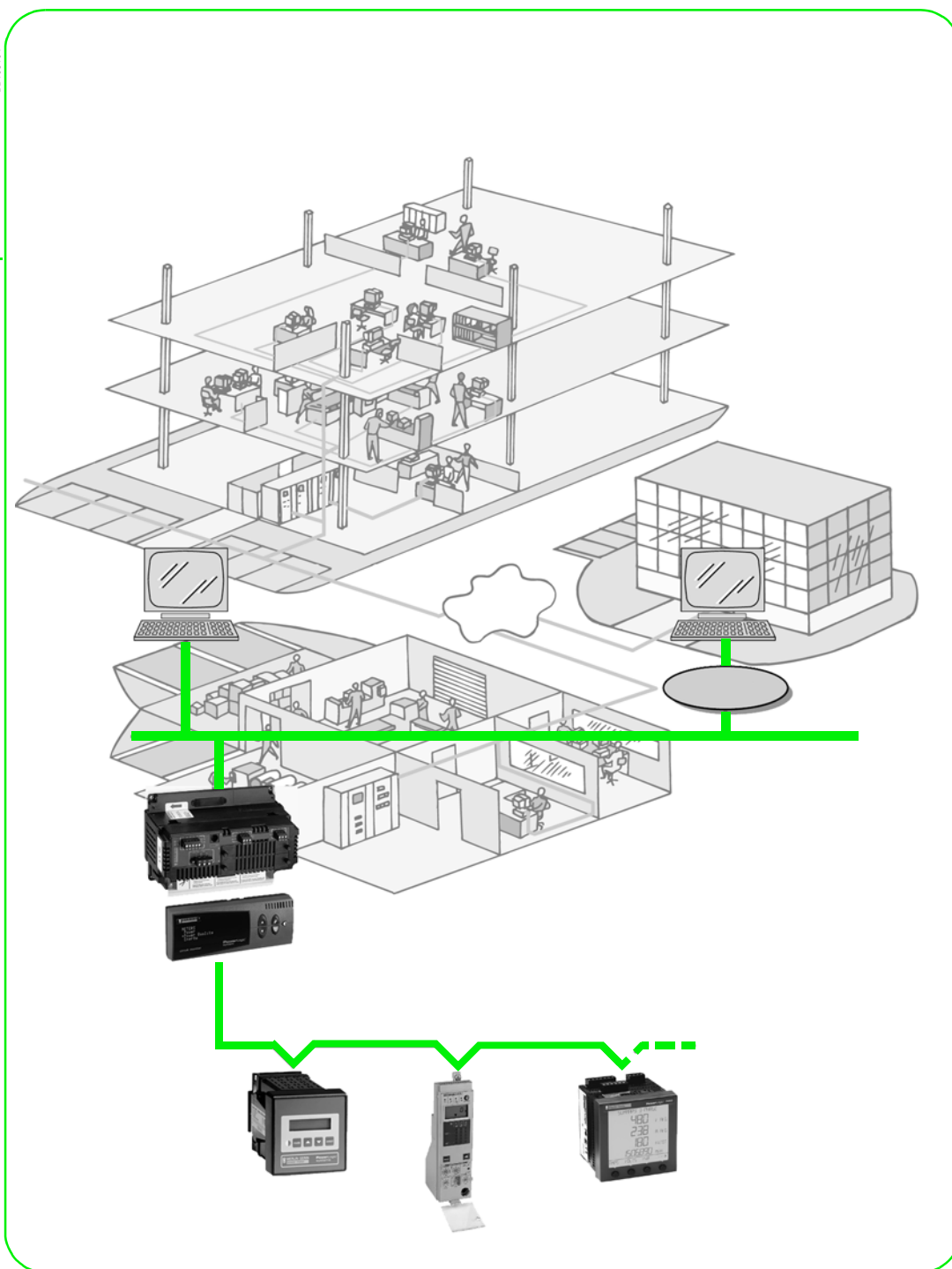|	ION8800			ION8600		
	A	B	C	A	B	C
Logging						
Min/max of instantaneous values	■	■	■	■	■	■
Data logging	■	■	■	■	■	■
Event logging	■	■	■	■	■	■
Trend curves	- (1)	-	-	-	-	-
Alarms	■	■	■	■	■	■
Alarm notification via email	■	■	■	■	■	■
Sequence of Events Recording	■ (2)	■	■	■	■	■
Date and time stamping	■	■	■	■	■	■
GPS time synchronisation	■	■	■	■	■	■
Storage capacity	up to 10 MB	up to 10 MB	up to 10 MB	10 MB	5 MB	2 MB
Display, sensors, input/outputs						
Front-panel display	■	■	■	■	■	■
Built-in current and voltage sensors	-	-	-	-	-	-
Pulse output	3	3	3	11	11	11
Digital or analogue inputs (max. number)	1	1	1	2	2	2
Digital or analogue outputs (max. number including pulse outputs)	13	13	13	14	14	14
Direct voltage connections without external VT	500 V			480 V		
Power supply						
AC/DC version — AC	85 to 240 V AC			120 to 277 V / 120 to 480 V / 57 to 70 V / 65 to 120 V / 160 to 277 V		
AC/DC version — DC	110 to 270 V DC (±10 %)			80 to 160 V / 200 to 350 V		
DC version	-	-	-	-	-	-
Communication						
RS 485 port	Option	Option	Option	■	■	■
Infra-red port	■	■	■	■	■	■
RS 232 port	Option	Option	Option	■	■	■
Modbus	M	M	M	M	M	M
Ethernet port (Modbus/TCP/IP protocol)	Option	Option	Option	Option	Option	Option
HTML Web-page server	Option	Option	Option	Option	Option	Option
Ethernet gateway for other products on an RS 485 link	Option	Option	Option	Option	Option	Option

(1) The ION8800 and ION8600 do trending with software.
(2) SER is manual process in ION meters.

ION7650	ION7550	ION7350	ION7330	ION7300	ION6200
■	■	■	■	■	-
■	■	■	■	-	-
■	■	■	■	-	-
■	■	■	-	-	-
■	■	■	■	-	-
■	■	■	-	-	-
■	■	■	■	-	-
■	■	■	■	-	-
■	■	■	■	-	-
up to 10 MB	up to 10 MB	300 kB	300 kB	-	-
■	■	■	■	■	■
-	-	-	-	-	-
20	20	8	8	4	-
1	1	-	-	-	2
12	12	8	8	8	2
600 V		600 V		690 V	
85 to 240 V		95 to 240 V		100 to 240 V	
110 to 300 V		120 V to 310 V		110 to 300 V	
-		20 to 60 V		-	
■	■	■	■	■	Option
■	■	■	■	■	-
■	■	-	-	-	-
M	M	M	M	M	M
Option	Option	Option	Option	Option	-
Option	Option	Option	Option	-	-
Option	Option	Option	Option	-	-

Harmonic-management solutions from Schneider Electric

Applications

Harmonic-management solutions from Schneider Electric

9.1 Analysis and diagnosis from Schneider Electric

Selection of the best solution, from both the technical and economic point of view, requires an in-depth study of the installation.

MV and LV diagnosis

When an expert from a Schneider Electric CEAT unit is called in, the user is guaranteed that the proposed solution will be effective (e.g. a guaranteed maximum THDu level).

The harmonic analysis and diagnosis are carried out by an engineer specialised in the field of disturbances in electrical distribution systems and equipped with powerful analysis and simulation equipment.

The service provided by Schneider Electric is divided into steps:
- measurement of disturbances, in current and in phase-to-neutral and phase-to-phase voltages, on the disturbing loads, on the disturbed outgoing circuits and the power sources
- a computer model of the measured phenomena is created, providing a precise explanation of their causes and optimised selection of the possible solutions
- a complete report is drawn up, indicating:
  □ the measured levels of disturbance
  □ the maximum permissible levels of disturbance (IEC 61000, IEC 60034, etc.)
- the performance of the selected solutions is guaranteed
- the final solution is implemented, using the selected equipment and systems.

The entire service is certified ISO 9002.

To facilitate on-site expert analysis, Schneider Electric proposes a portable version of the CM4000-4000T
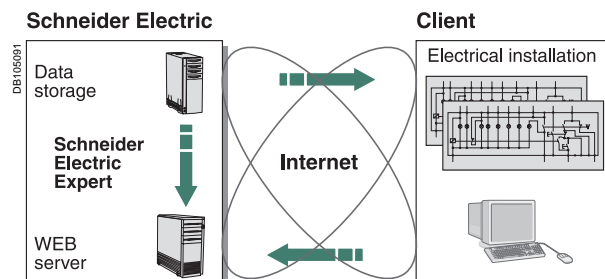

Portable CM4000.

Portable CM4000 in action.

Remote monitoring of electrical installations via Internet
- analyses a consumption profile to control energy costs
- monitors, identifies and anticipates installation failures.

Passive filter.

Active filter of MGE UPS SYSTEMS.

Hybrid filter.

9.2 Specific Schneider Electric products

9.2.1 Passive filters

Passive filters are made up of inductors and capacitors set up as resonant circuits tuned to the frequency of the harmonic order to be eliminated. A system may comprise a number of filters to eliminate several harmonic orders.

General characteristics	
Voltage	400 V three phase
Power rating	Up to 265 kvar/470 A for the 5th order filter Up to 145 kvar/225 A for the 7th order filter Up to 105 kvar/145 A for the 11th order filter
Enclosure	Prisma

9.2.2 Active filters of MGE UPS SYSTEMS
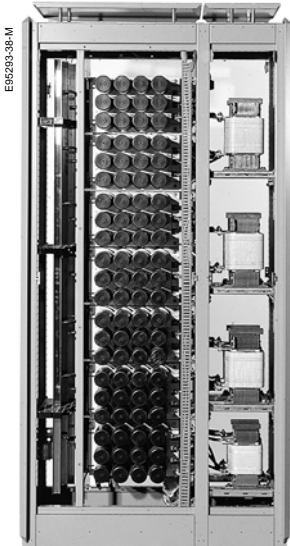
General characteristics	
Voltage	400 V
Conditioning capacity per phase (A rms)	20 to 120 A rms
Conditioned harmonic currents	Orders 2 to 25, complete spectrum or selected orders
Harmonic attenuation	Load THDi / Upstream THDi greater than 10 at rated load on conditioner
Functions	Displacement power-factor correction 7-language alphanumeric display Diagnosis and maintenance system Parallel connection Remote control Communications interface JBus/RS485

9.2.3 Hybrid filters

Hybrid filters combine the advantages of a passive filter and a SineWave active harmonic conditioner in a single unit.

General characteristics	
Passive filter	5th order harmonics
Active harmonic conditioner	20 to 180 A
Voltage	400 V three phase
Reactive energy compensation	Up to 265 kvar
Harmonic orders conditioned	2 to 25
Total harmonic current	Up to 440 A
Enclosure	Prisma

Harmonic-management solutions from Schneider Electric

9.3 Selection guide

Type of application	Rectiphase passive filter	SineWave MGE UPS SYSTEMS conditioner	Rectiphase hybrid filter
Commercial buildings (computer systems, air-conditioning, lighting, lifts)	■	■ ■ ■	■ ■
Paper, cardboard, plastics industry (conveyers, winding/unwinding equipment)	■ ■ ■	■	■ ■
Water-treatment (pumps, mixers)	■ ■	■ ■ ■	■ ■ ■
Handling (cranes, ski lifts)	■ ■	■	■ ■ ■

Key:
■ ■ ■ : perfectly suited
■ ■   : perfectly suited technically, but costly
■   : satisfactory

Bibliography

■ ISF: Technical Seminar: **"Understanding and managing harmonics"** (in French)

■ ISF: Technical Publications: **"Harmonics in electrical installations"** (in French)

■ IEC standards

■ Utility recommendations

■ EDF: Harmonique 5.1 software, User Manual (in French)

■ EDF: *Les cahiers de l'Ingénierie:* Management of harmonics on industrial and commercial distribution systems, Parts 1 and 2 (Ref. GEDO 1.48.B.07/96 and 1.48.B.01/97) (in French)

■ Merlin Gerin: Guide to reactive-energy compensation and harmonic filtering - HV/MV (Ref. CG0065)

■ Schneider Electric: "Cahiers Techniques" publications nos. 152, 159, 160, 183.

As standards, specifications and designs change from time to time, please ask for confirmation
of the information given in this publication.

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